

Why does AM2 have a warm and dry bias over the U. S. Southern Great Plains in summer?

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Outline

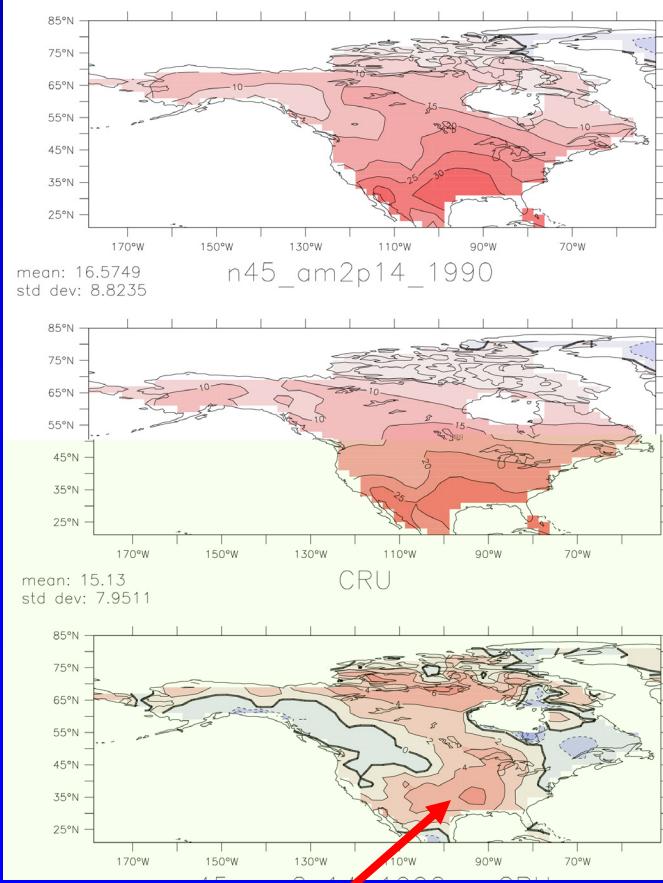
- **The bias**
- **Using short range forecasts of AM2 to study the bias**
- **Using Single Column Model (SCM) integrations with AM2 physics to study the bias**



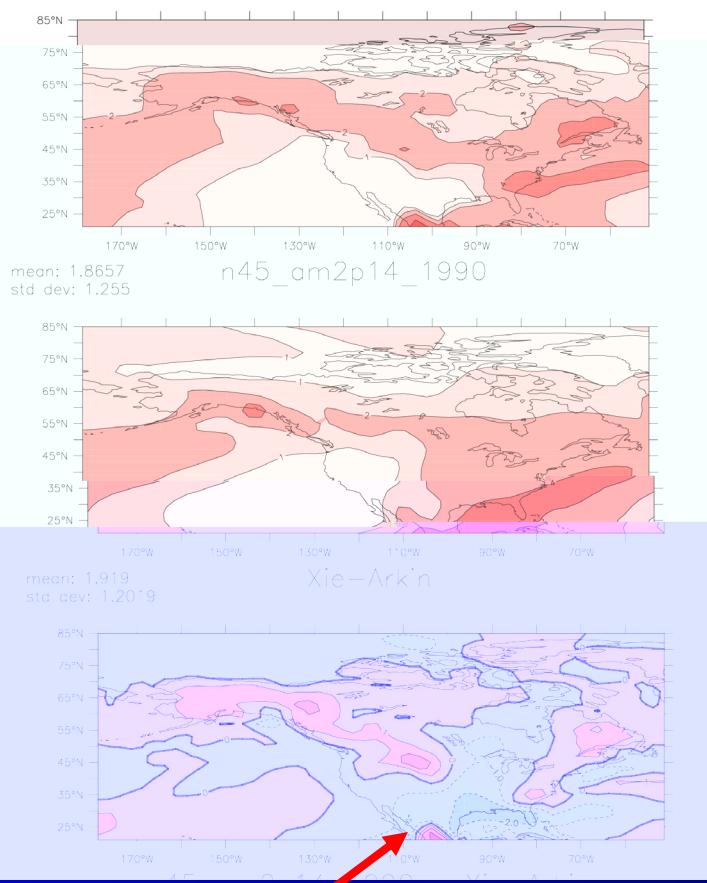
The summertime bias over the SGP in the GFDL AGCM

model minus observation model

2 meter temperature (K)



Precipitation (mm day^{-1})



warm bias > 6K

dry bias > 2 mm day^{-1}

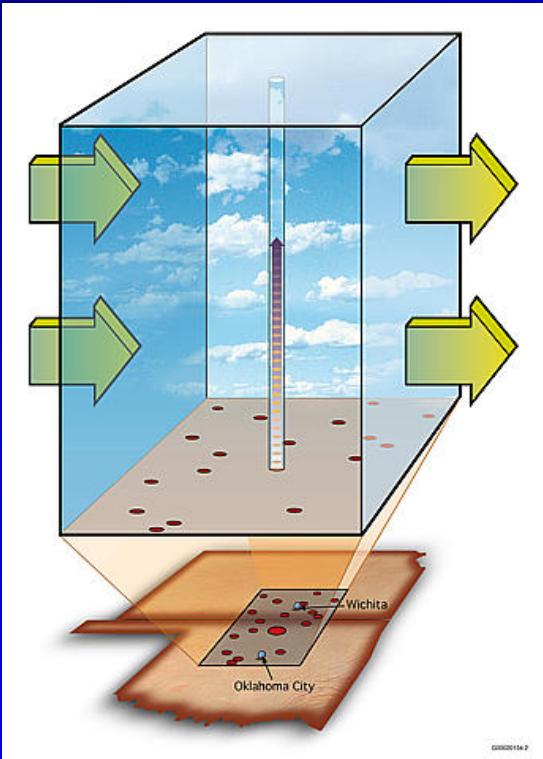


Can we understand this bias?

- One technique available to us is short-range forecasts whereby the model is initialized with the observed state and we can analyze its drift towards its preferred climate state
- Here we perform short-range forecasts (3 days) starting every day at 00Z for the duration of the June-July 1997 Intensive Observing Period (IOP) and analyze output at the locations of the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site



ARM Data



- 5 sounding stations (every 3 hours during IOPs)
 - 7 wind profilers
 - Surface flux (sensible, latent, CO₂) and radiation estimates from multiple surface stations
 - Precipitation estimates from radar calibrated to gauge data
 - Satellite estimates of top-of-atmosphere radiation budget (geostationary data calibrated to CERES)
- + NCEP Regional Model (RUC) background fields

Variational Analysis (*Zhang and Lin 1997, Zhang et al. 2001*)

- The profiles of state variables are adjusted until they satisfy column budgets of mass, energy, and moisture
- This provides an estimate of the large-scale flow and the diabatic heat and moisture tendencies



Initial conditions for AM2 forecasts

- Atmospheric State

Initial conditions from the ECMWF re-analysis (“ERA-40”) transposed to the AM2 grid respecting the differences in orography

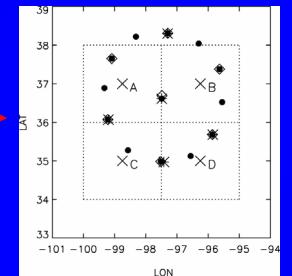
No assimilation is done

- Initialization of the land-surface

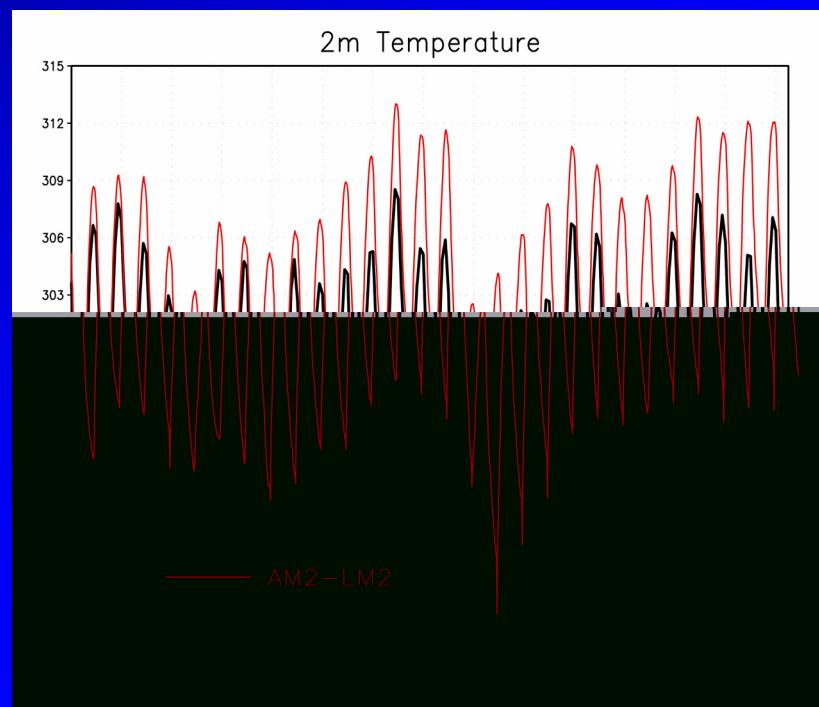
Land model is run offline with ERA-40 meteorology and observations of precipitation



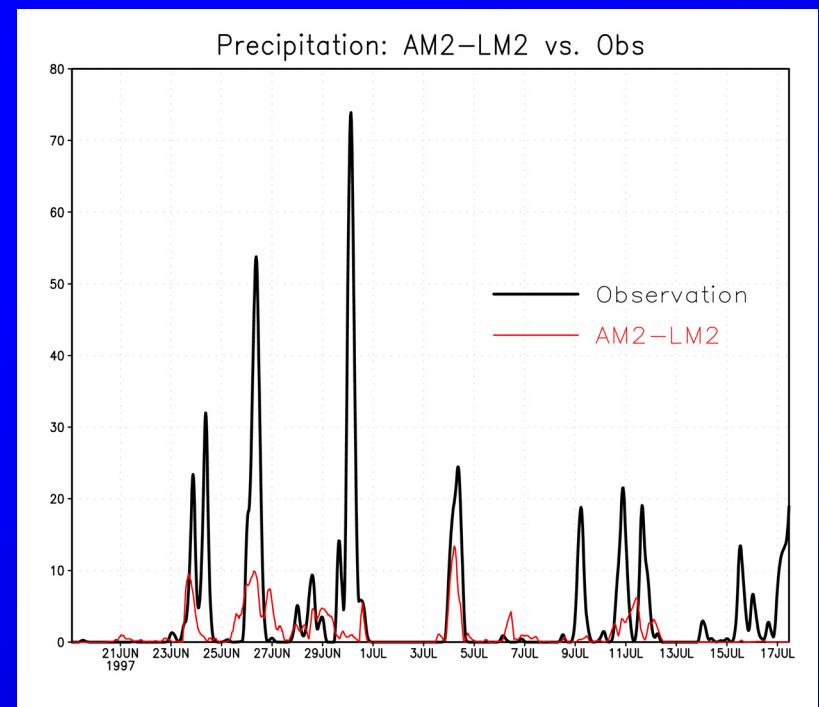
GCM forecast results for the ARM SGP: → Hours 12-36



2 meter temperature (K)



Precipitation (mm day^{-1})

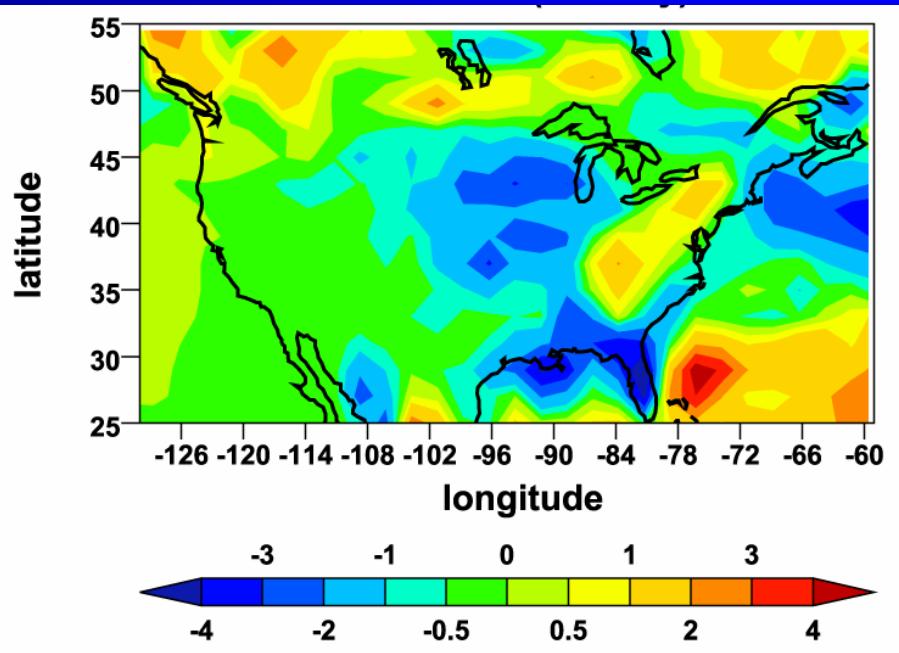


Again warm and dry!

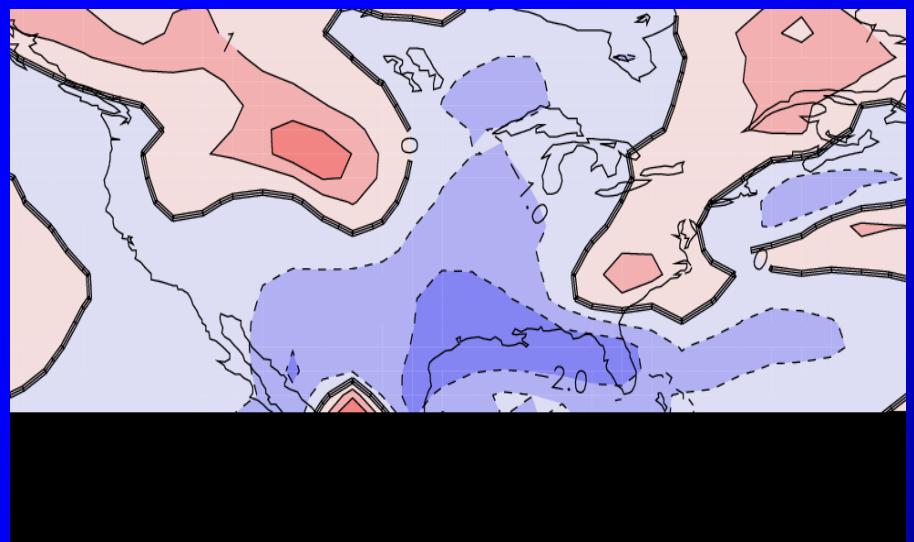


Precipitation Bias (AM2 Minus Observations)

1st Day Forecast Bias



Climate Bias



(mm day⁻¹)

Climate bias appears from the very beginning of the forecasts!



Why warm in the first few days?

ARM measured surface energy balance

Large over-estimate of net-surface solar radiation ($\sim 40 \text{ W m}^{-2}$)

- much larger on wet days than on dry days
- confirmed by satellite observations

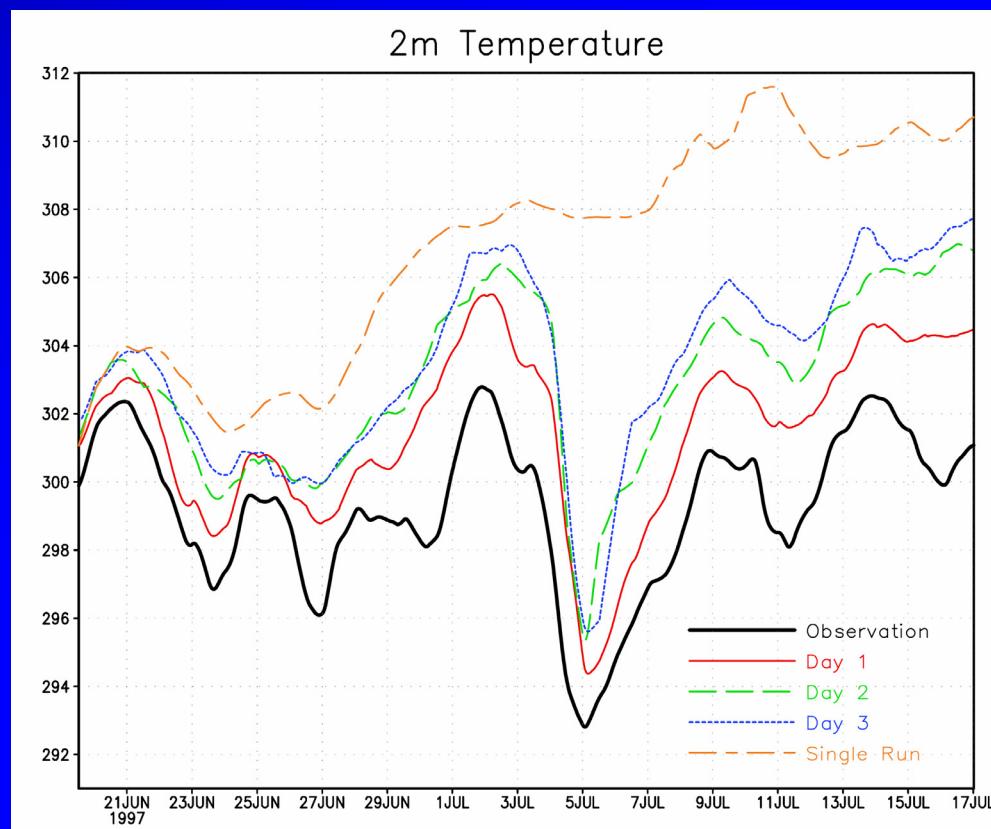
Large over-estimate of surface sensible heat flux ($\sim 40 \text{ W m}^{-2}$)

Evaporation only slightly underestimated (100 vs 115 W m^{-2})



Climate Drift

24-hour running mean 2-meter temperature



Single forecast from
the start of the IOP

Day 3

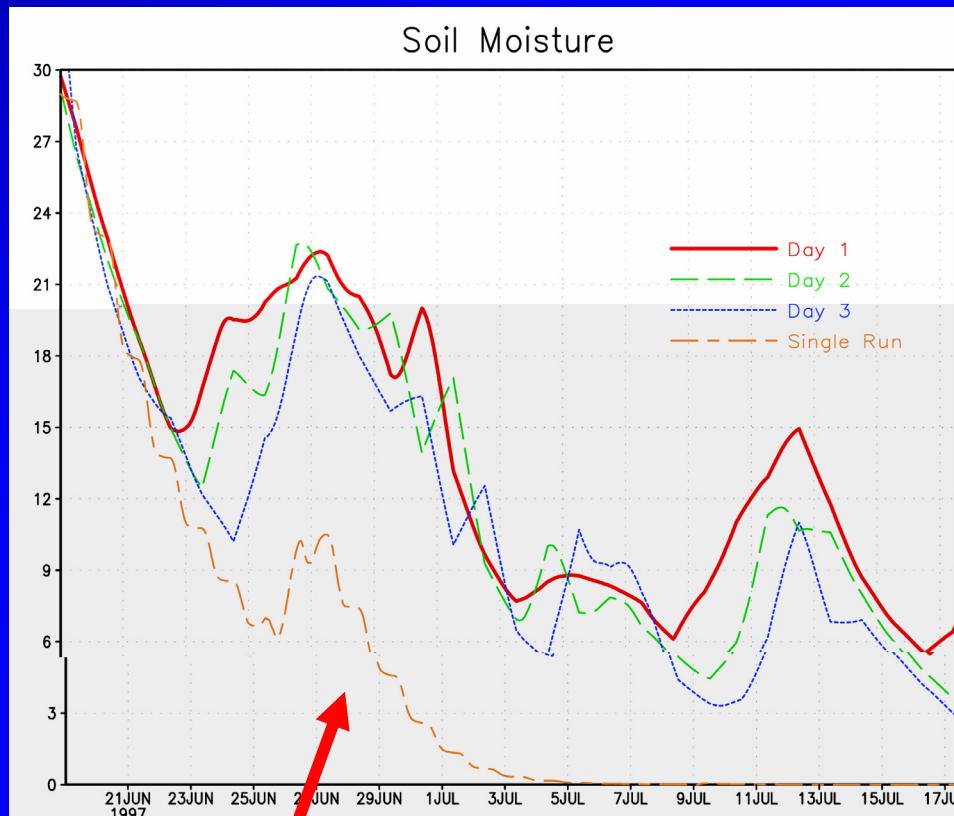
Day 2

Day 1

Observation



Climate drift is tied to the lack of precipitation



Day 1
Day 2
Day 3

Single forecast from the start of the IOP



Intermediate summary

- The GFDL model when given initial conditions fails to produce enough precipitation
- This leads to an overestimate of solar radiation which causes an initial warm bias
- The lack of precipitation leads to the soil drying out and once the soil is dry, solar energy can only be balanced by sensible + longwave heat loss which strengthens the warm bias
- The lack of evaporation from the dry soil causes a further reduction of precipitation

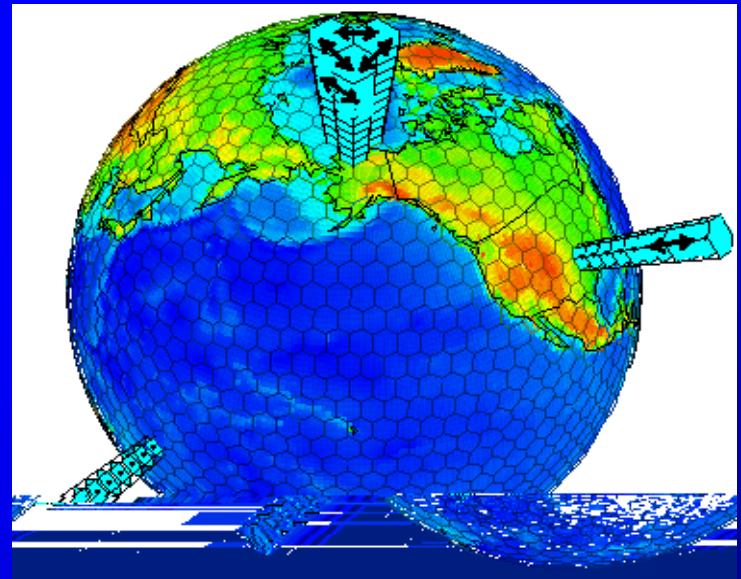
*So why can't the GFDL model generate enough precipitation?
Is it the physics? Is it the dynamics? Is it both?*



What can we learn from SCM tests?

- A Single Column Model is a one-dimensional simulation of the atmosphere using only the “column physics” from the global model
- This can be driven with data to simulate an observed period – and is an alternative to weather forecasting

Single Column Model
(SCM)



The SCM/CRM Forcing Approach

“Advection Forcing” computed
from observations

$$\frac{\partial s}{\partial t} = -V \bullet \nabla s - \omega \frac{\partial s}{\partial p}$$

$$\frac{\partial q}{\partial t} = -V \bullet \nabla q - \omega \frac{\partial q}{\partial p}$$

“Physics” computed from:

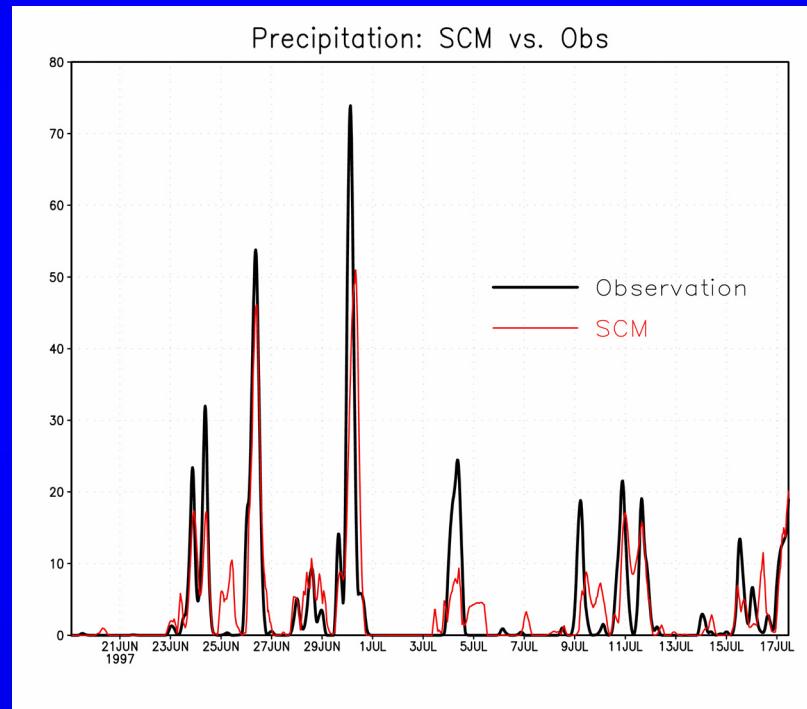
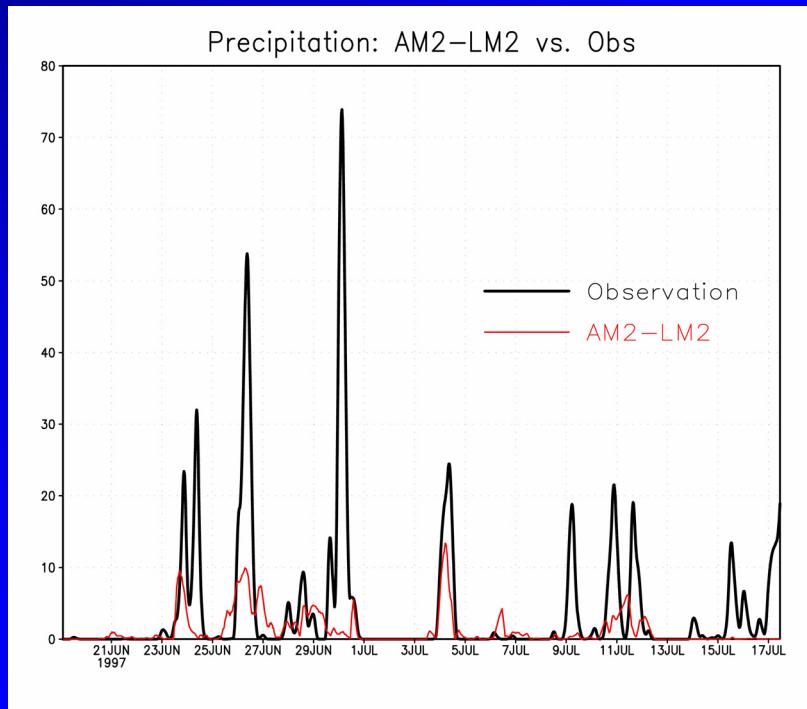
- CRM “explicitly”
- SCM parameterizations

$$+ L(c - e) - \frac{\partial \bar{\omega}' s'}{\partial p} + Q_{rad}$$

$$+ (e - c) - \frac{\partial \bar{\omega}' q'}{\partial p}$$



What can we learn from SCM tests?



SCM has much smaller solar radiation errors

(+ 24 W m⁻² at the surface but - 4 W m⁻² at the top-of-atmosphere)



Differences between the SCM and the GCM

Surface fluxes

- Sensible heat: 80 W m^{-2} in the GCM versus 40 W m^{-2} in the observations
- Latent heat: 100 W m^{-2} in the GCM versus for 115 W m^{-2} in the observations

I don't think this is likely to be the reason that the GCM underestimates precipitation

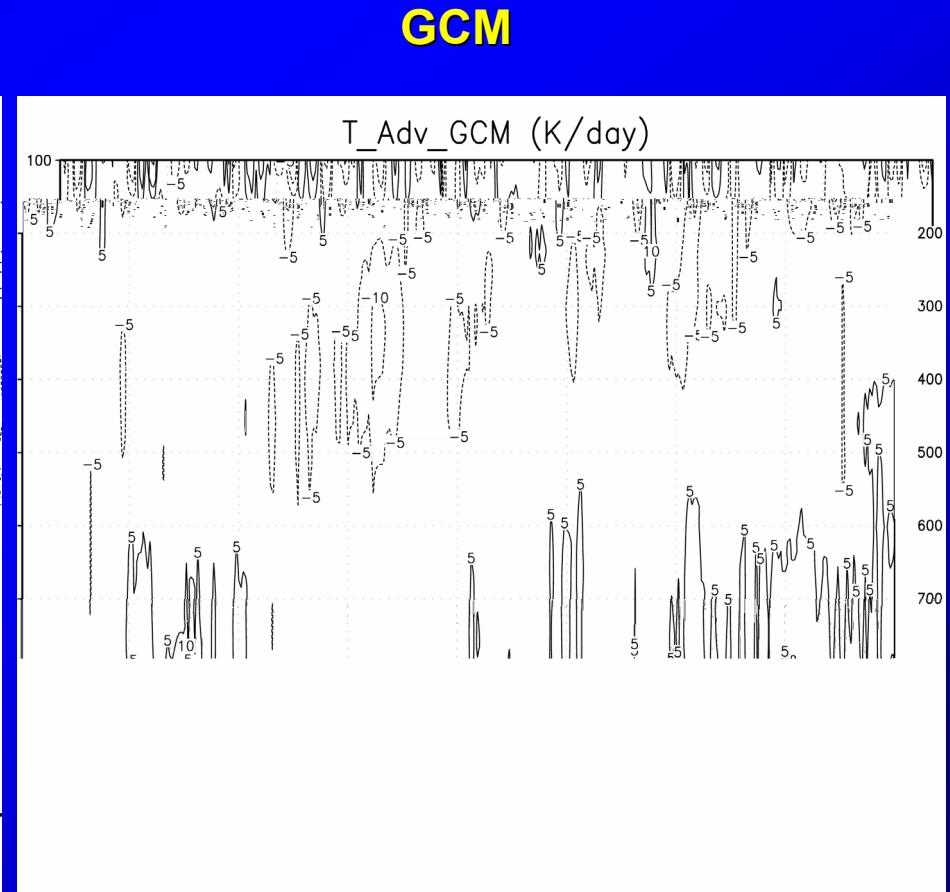
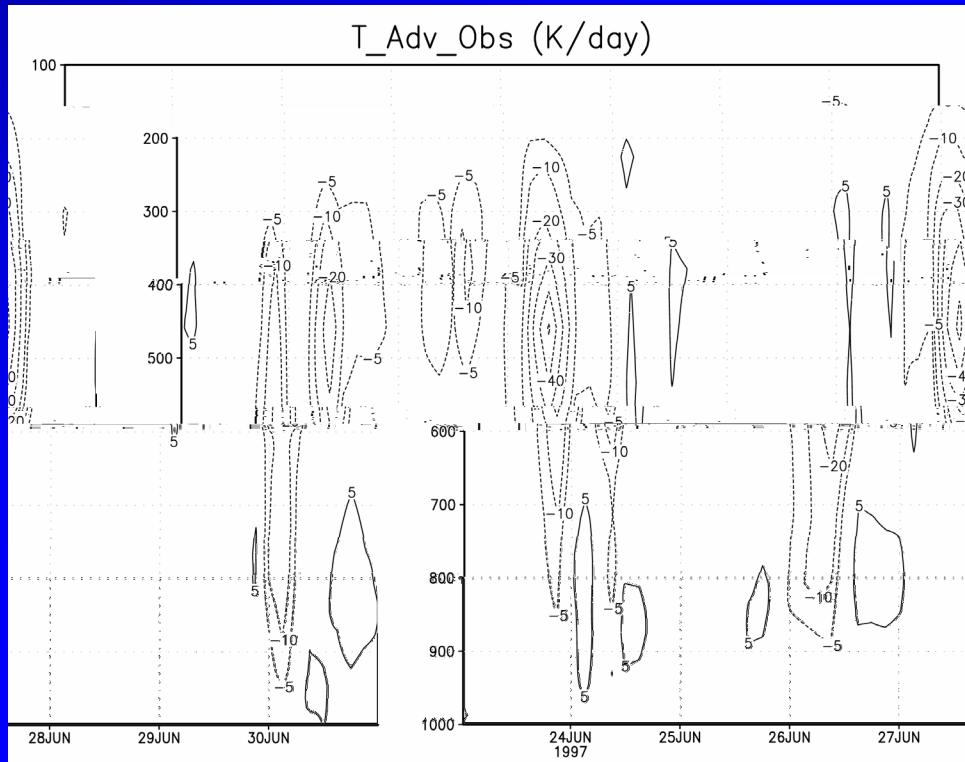
If I were to give the SCM the GCM's heat fluxes this would increase the moist static energy input by 25 W m^{-2} . Would that reduce the precipitation by 75%?



Differences between the SCM and the GCM

Dynamical Forcing

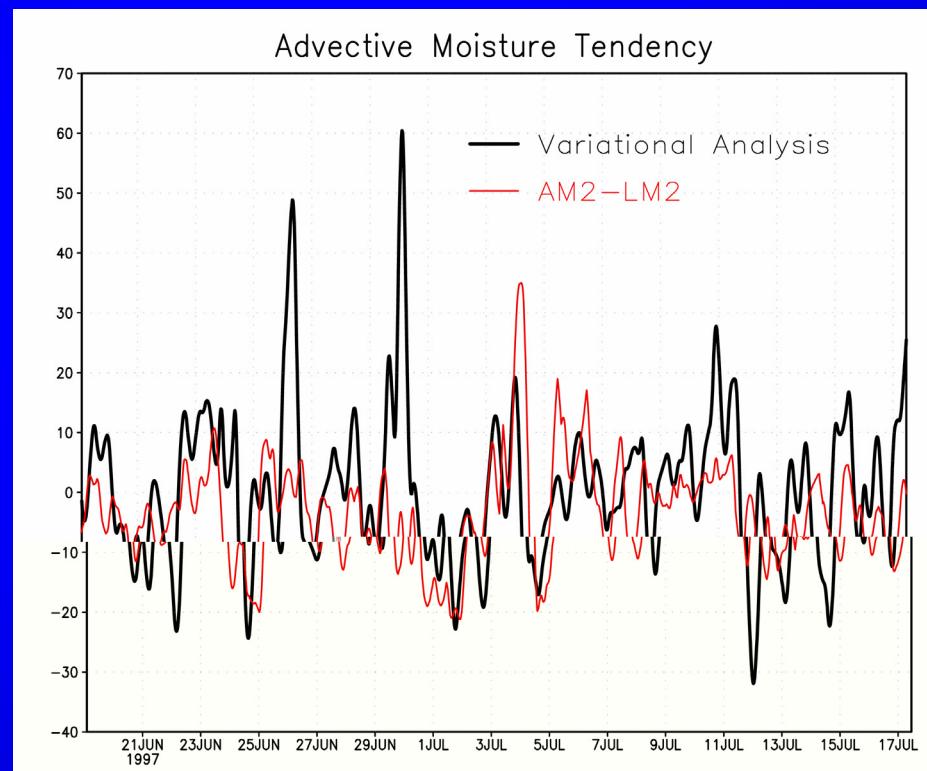
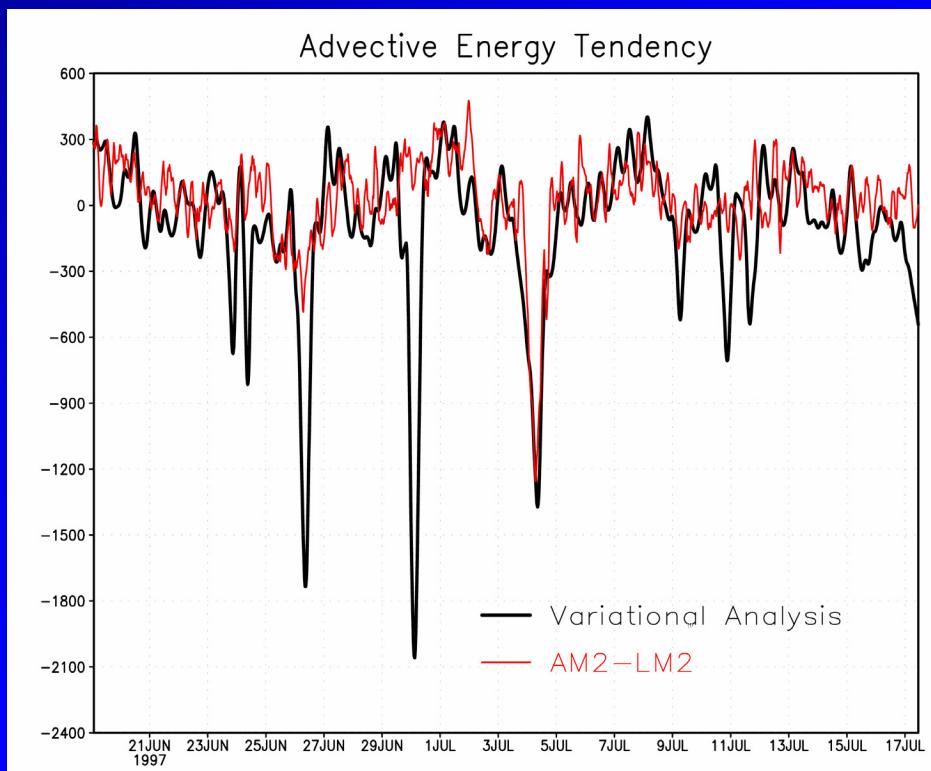
Variational Analysis



Column Integrated Advective Tendencies

Energy (W m^{-2})

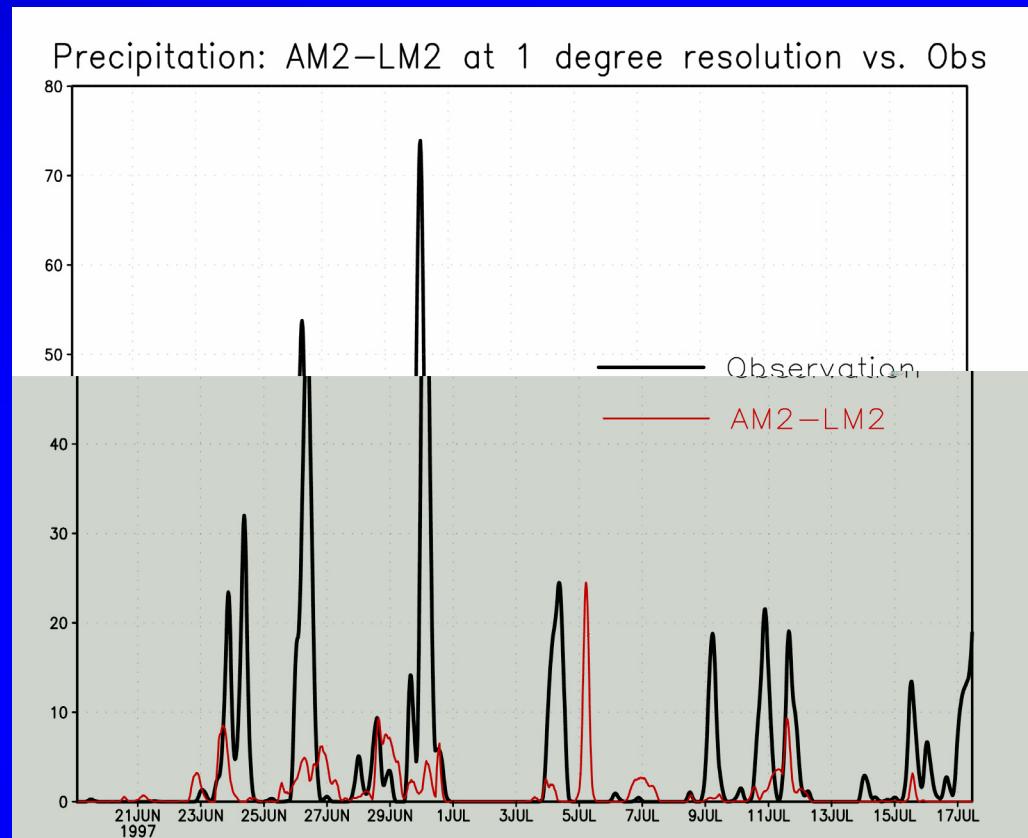
Moisture (mm day^{-1})



What is the solution?

Increased resolution?

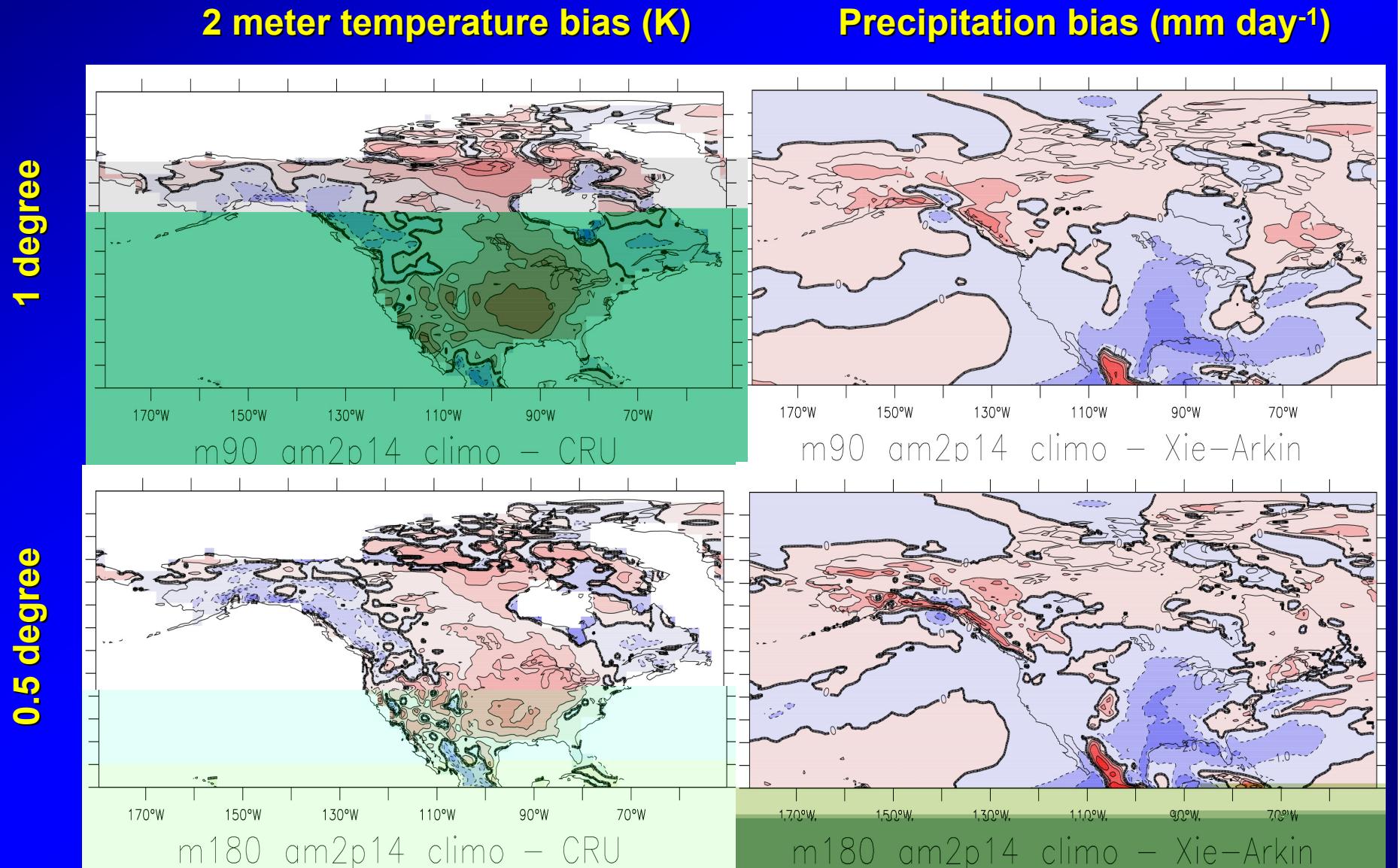
1 degree AM2



Not obviously!

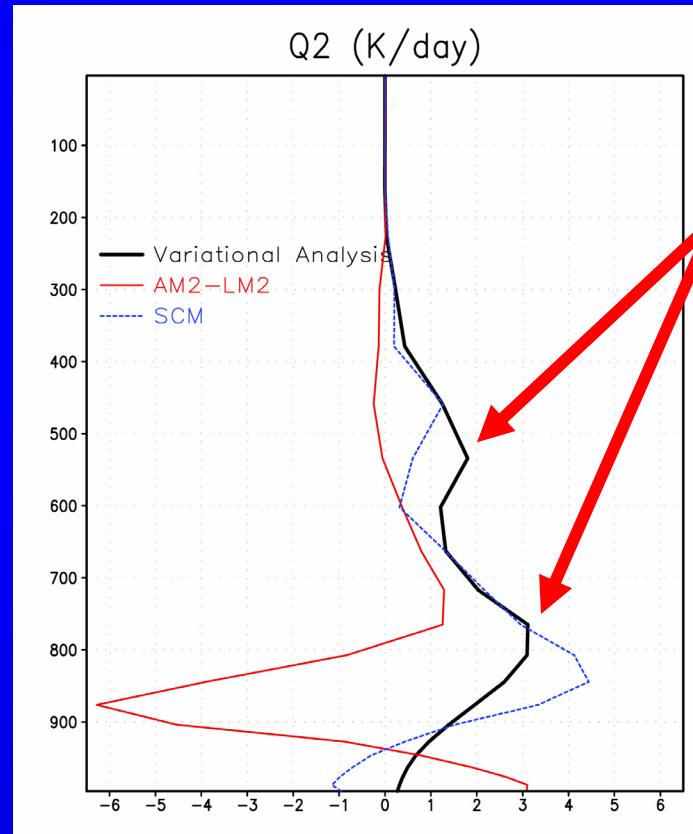
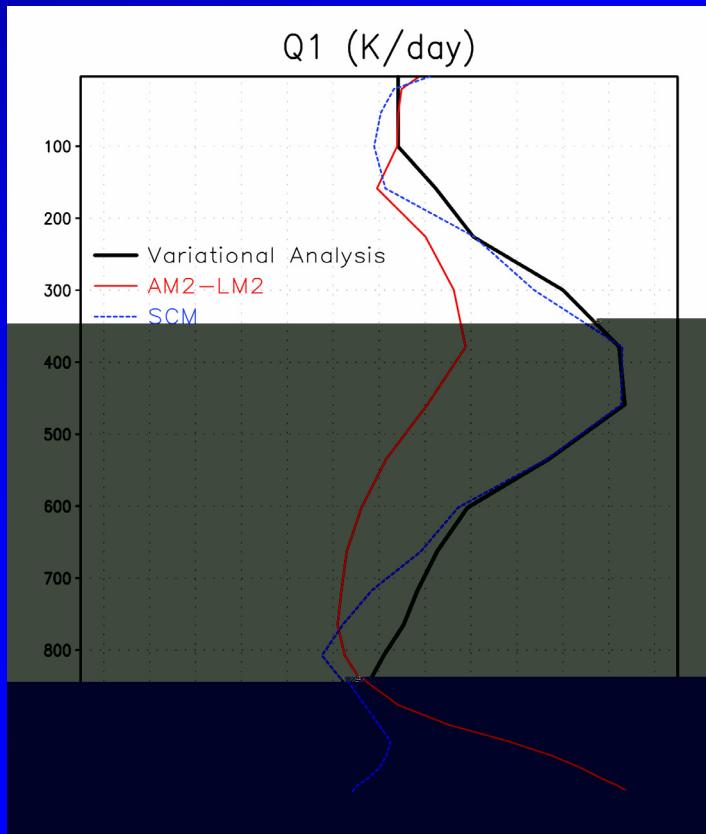


Increased horizontal resolution is apparently not the answer (at least not yet)



Is the physics good enough?

Heat & Moisture Source/sinks on Wet Days



Convective precipitation evaporation at too high a level or lack of stratiform precipitation?



A multitude of other sensitivity tests have been performed

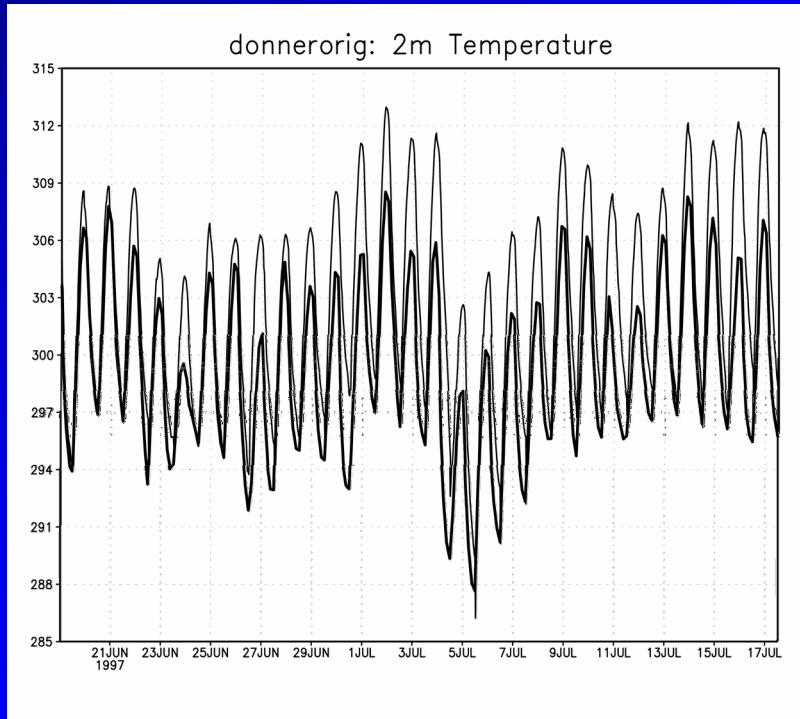
- *Convection*
 - no a-ratio or critical cloud work function
 - no Tokioka lateral entrainment rate minimum
 - enhanced convective precipitation evaporation
- *PBL mixing*
 - no enhanced mixing in the stable boundary layer
- *Land*
 - removal of artificially reduced near surface heat capacity
- *Dynamics*
 - no horizontal wind divergence damping in N90

None of these tests raise the precipitation over the period above 1.5 mm day⁻¹ (observed = 4.1 mm day⁻¹)!

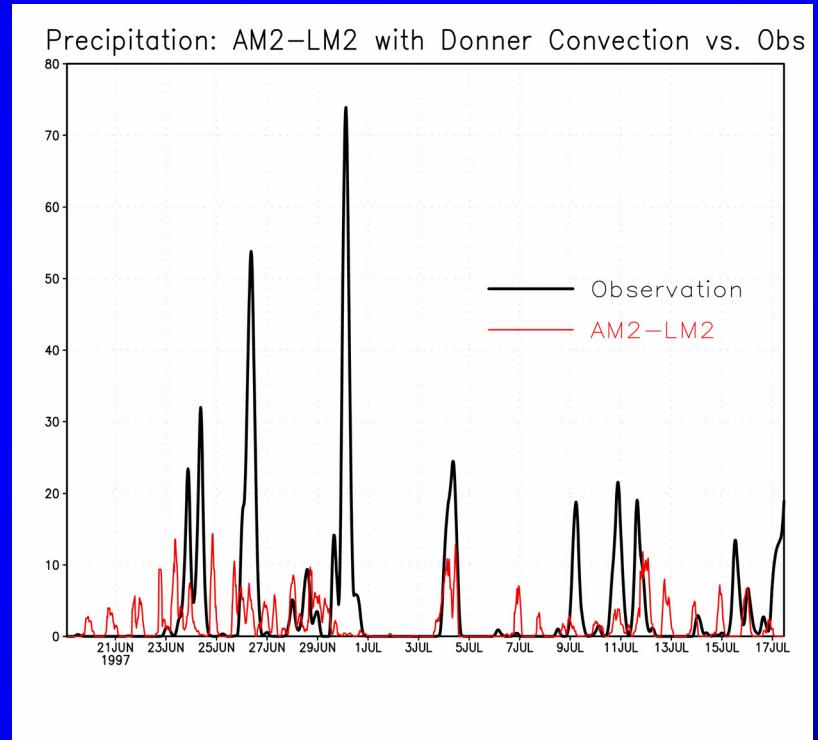


Simulations with Donner convection

2 meter temperature (K)



Precipitation (mm/day)



- More precipitation (2 mm day^{-1})
- Convective/Stratiform precipitation balance (2:1) as observed
- Precipitation still only 50% of observed
- Artificial diurnal cycle



Summary

- GFDL's AM2 warm & dry bias appears to be due to a lack of precipitation
- SCM tests show that when given the observed dynamical forcing the precipitation and radiation balance is sufficient
- Getting the right dynamical forcing is key

The interaction between physics and dynamics is crucial to getting precipitation events of the right magnitude. How to fix this?

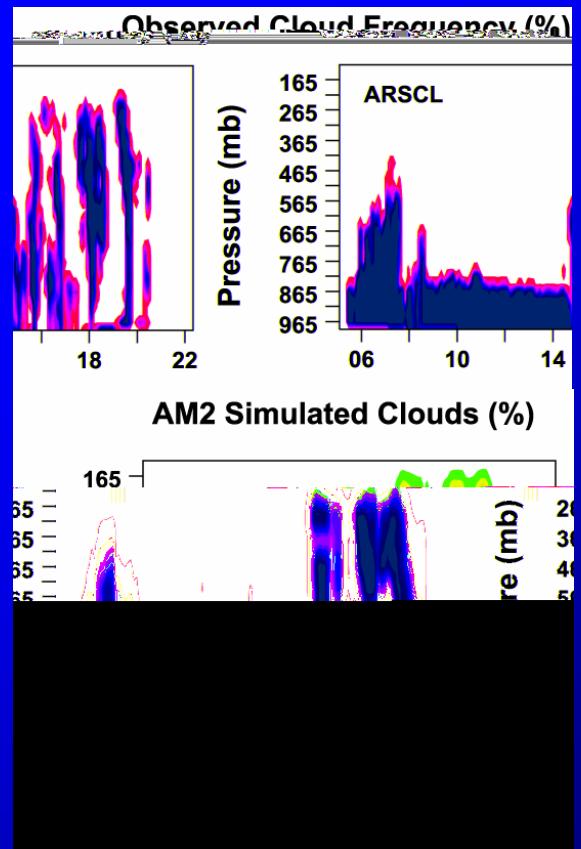


Future AM2 Forecasting Experiments and Analyses

- ARM Mixed-Phase Arctic Cloud Experiment (Barrow, Alaska, October 2004)
- TOGA-COARE (Tropical West Pacific Warm Pool, Winter 1992-1993) (by *Robert Pincus and Xu Wei at CDC*)
- “Real-time” forecasts to compare to CloudSat which will be launched early November 2005



M-PACE Clouds



October 2004

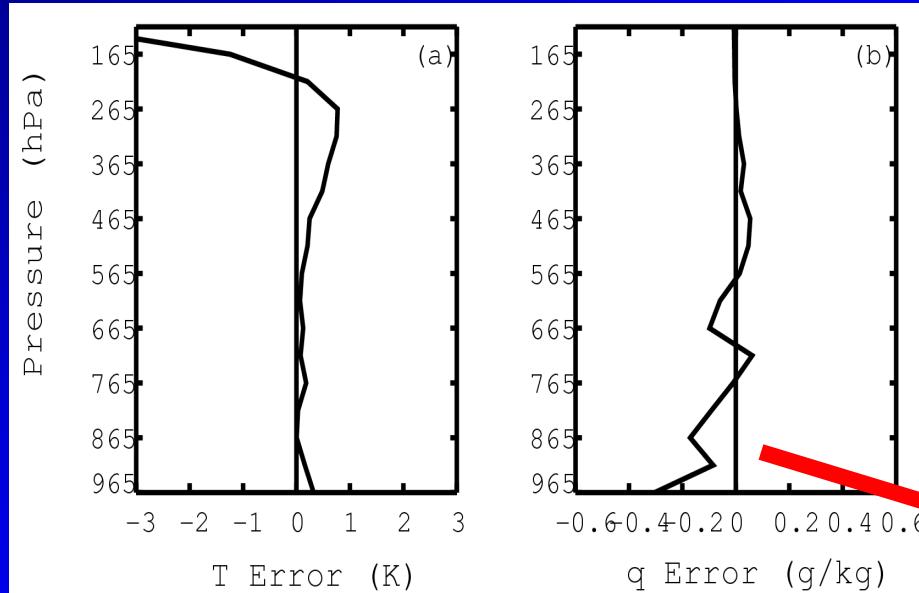


A wide-angle photograph of a serene mountain lake. The water is extremely still, creating a perfect mirror that reflects the surrounding environment. In the background, a large, rugged mountain range with light-colored, possibly granite, rock faces rises against a clear, pale blue sky. The base of the mountains is covered with a dense forest of tall, dark evergreen trees. A small, dark peak is visible on the right side of the frame. The overall atmosphere is peaceful and natural.

The End

Accuracy of ERA-40 data at the ARM SGP site

Mean
Bias
Error
(ERA40
– ARM)



RMS
Error
(solid)
Std. Dev.
Obs
(dashed)

